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Farm income and production impacts of using GM crop technology 1996–2015

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ABSTRACT

This paper provides an assessment of the value of using genetically modified (GM) crop technology in agriculture at the farm level. It follows and updates earlier annual studies which examined impacts on yields, key variable costs of production, direct farm (gross) income and impacts on the production base of the 4 main crops of soybeans, corn, cotton and canola. The commercialisation of GM crops has occurred at a rapid rate since the mid 1990s, with important changes in both the overall level of adoption and impact occurring in 2015. This annual updated analysis shows that there continues to be very significant net economic benefits at the farm level amounting to $15.4 billion in 2015 and $167.8 billion for the 20 year period 1996–2015 (in nominal terms). These gains have been divided 49% to farmers in developed countries and 51% to farmers in gains with the remaining 28% coming from cost savings. The technology has also made important contributions to increasing global production levels of the 4 main crops, having, for example, added 180 million tonnes and 358 million tonnes respectively, to the global production of soybeans and maize since the introduction of the technology in the mid 1990s.

KEYWORDS:

cost | genetically modified crops | income | production | yield

INTRODUCTION

2015 represents the twentieth year of widespread cultivation of crops containing genetically modified (GM) traits, with the global planted area of GM-traited crops at about 172 million hectares.

During this 20-year period, there have been many papers assessing the farm level 'economic' and farm income impacts associated with the adoption of this technology. The authors of this paper have, since 2005, engaged in an annual exercise to aggregate and update the sum of these various studies, and where possible and appropriate, to supplement this with new analysis. The aim of this has been to provide an up to date and as accurate as possible assessment of some of the key farm level 'economic' impacts associated with the global adoption of crops containing GM traits. It is also hoped the analysis continues to contribute to greater understanding of the impact of this technology and to facilitate more informed decision-making, especially in countries where crop biotechnology is currently not permitted.

This study updates the findings of earlier analysis into the global impact of GM crops since their commercial introduction in 1996 by integrating data and analysis for 2015. Previous analysis by the current authors has been published in various journals, including AgbioForum 12 (Brookes and Barfoot, 2009) (2), 184–208, the International Journal of Biotechnology (Brookes and Barfoot, 2011), vol 12, 1/2, 1–49 and GM Crops 3:4, 265–272 (Brookes and Barfoot, 2012), GM Crops 4:1, 1–10 (Brookes and Barfoot, 2013), GM Crops 5:1, 65–75 (Brookes and Barfoot, 2014), GM Crops 6: 13–46 (Brookes methodology and analytical procedures in this present discussion are unchanged to allow a direct comparison of the new with earlier data. Readers should however, note that some data presented in this paper are not directly comparable with data presented in previous analysis because the current paper takes into account the availability of new data and analysis (including revisions to data for earlier years).

To save readers of this paper the chore of consulting the past papers for details of the methodology and arguments, these are included in full in this updated paper.

The analysis concentrates on gross farm income effects because these are a primary driver of adoption among farmers (both large commercial and small-scale subsistence). It also quantifies the (net) production impact of the technology. The authors recognize that an economic assessment could examine a broader range of potential impacts (eg, on labor usage, households, local communities and economies).

However, these are not included because undertaking such an exercise would add considerably to the length of the paper and an assessment of wider economic impacts would probably merit a separate assessment in its own right.

RESULTS AND DISCUSSION

HT Crops

The main impact of GM HT (largely tolerant to the broad-spectrum herbicide glyphosate) technology has been to provide more cost effective (less expensive) and easier weed control for farmers. Nevertheless, some users of this technology have also derived higher yields from better weed control (relative to weed control obtained from conventional technology). The magnitude of these impacts varies by country and year, and is mainly due to prevailing costs of different herbicides used in GM HT systems versus conventional alternatives, the mix and amounts of herbicides applied, the cost farmers pay for accessing the GM HT technology and levels of weed problems. The following important factors affecting the level of cost savings achieved in recent years should be noted:

- The mix and amounts of herbicides used on GM HT crops and conventional crops are affected by price and availability of herbicides. Herbicides used include both protected' chemistry, with availability affected by commercial decisions of suppliers to market or withdraw products from markets and regulation (eg, changes to approval processes). Prices also vary by year and country. For example, in 2008–2009, the average cost associated with the use of GM HT technology globally increased significantly relative to earlier years because of the increase in the global price of glyphosate relative to changes in the price of other herbicides commonly used on conventional crops. This abated in 2010 with a decline in the price of glyphosate back to previous historic trend levels;

- The amount farmers pay for use of the technology varies by country. Pricing of technology (all forms of seed and crop protection technology, not just GM technology) varies according to the level of benefit that farmers are likely to derive from it. In addition, it is influenced by intellectual property rights (patent protection, plant breeders' rights and rules relating to use of farm-saved seed). In countries with weaker intellectual property rights, the cost of the technology tends to be lower than in countries where there are stronger rights. This is examined further in c) below;

- Where GM HT crops (tolerant to glyphosate) have been widely grown, some incidence of weed resistance to glyphosate has occurred and resistance has become a major concern in some regions. This has been attributed to how glyphosate was used; because of its broad-spectrum post-emergence activity, it was often used as the sole method of weed control. This approach to weed control put tremendous selection pressure on weeds and as a result contributed to the evolution of weed populations predominated by resistant individual weeds. It should, however, be noted that there are hundreds of resistant weed species confirmed in the International Survey of Herbicide Resistant Weeds (www.weedscience.com). Worldwide, there are 36 weed species that are currently (accessed February 2017) resistant to glyphosate, compared with 159 weed species resistant to ALS herbicides (eg, chlorimuron ethyl commonly used in conventional soybean crops) and 74 weed species resistant to photosystem II inhibitor herbicides (eg, atriazine commonly used in corn production). In addition, it should be noted that the adoption of GM HT technology has played a major role in facilitating the adoption of no and reduced tillage production techniques in North and South America. This has also probably contributed to the emergence of weeds resistant to herbicides like glyphosate and to weed shifts toward those weed species that are increasingly being advised to be more proactive and include other herbicides (with different and complementary modes of action) in combination with glyphosate in their weed management systems, even where instances of weed resistance to glyphosate have not been found. This change in weed management emphasis also reflects the broader agenda of developing strategies across all forms of cropping systems to minimise and slow down the potential for weeds developing resistance to existing technology solutions (Norsworthy et al., 2012). At the macro level, these changes have influenced the mix, total amount, cost and overall profile of herbicides applied to GM HT crops. Relative to the conventional alternative, however, the economic impact of the GM HT crop use has continued to offer important advantages for most users. It should also be noted that many of the herbicides used in conventional production systems had significant resistance issues themselves in the mid 1990s. This was one of the reasons why glyphosate tolerant soybeans were rapidly adopted, as glyphosate provided good control of these weeds. If the GM HT technology was no longer delivering net economic benefits, it is likely that farmers around the world would have significantly reduced their adoption of this technology in favor of conventional alternatives. The fact that GM HT global crop adoption levels have not fallen in recent years suggests that farmers must be continuing to derive important economic benefits from using the technology.

These points are further illustrated in the analysis below.

GM HT Soybeans

The average impacts on gross farm level profitability from using this technology are summarised in Table 1. The main farm level gain experienced has been a reduction in the cost of production, mainly through reduced expenditure on weed control (herbicides). Not surprisingly, where yield gains have occurred from improvements in the level of weed control, the average farm income gain has tended to be higher, in countries such as Romania, Mexico and Bolivia. A second generation of GM HT soybeans became available to commercial soybean growers in the US and Canada in 2009. This technology offered the same tolerance to glyphosate as the first generation (and the same cost saving) but with higher yielding potential. The realization of this potential is shown in the higher average gross farm income benefits (Table 1).

TABLE 1. GM HT soybeans: Summary of average gross farm level income impacts 1996–2015 ($/hectare).

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GM HT soybeans have also facilitated the adoption of no tillage production systems, shortening the production cycle. This advantage has enabled many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season. This second crop, additional to traditional soybean production, has added considerably to farm incomes and to the volumes of soybean production in countries such as Argentina and Paraguay.

Overall, in 2015, GM HT technology in soybeans (excluding second generation 'Intacta' soybeans: see below) has boosted gross farm incomes by $3.82 billion, and since 1996 has delivered $50 billion of extra farm income. Of the total cumulative farm income gains from using GM HT soybeans, $23.6 billion (47%) has been due to yield gains/second crop benefits and the balance, 53%, has been due to cost savings.

GM HT and IR (Intacta) Soybeans

This combination of GM herbicide tolerance (to glyphosate) and insect resistance in soybeans was first grown commercially in 2013, in South America. In the first 3 years, the technology was used on approximately 22.3 million hectares and contributed an additional $2.4 billion to gross farm income of soybean farmers in Argentina, Brazil, Paraguay and Uruguay, through a combination of cost savings (decreased expenditure on herbicides and insecticides) and higher yields (see Table 1).

GM HT Maize

The adoption of GM HT maize has mainly resulted in lower costs of production, although yield gains from improved weed control have arisen in Argentina, Brazil and the Philippines (Table 2).

TABLE 2. GM HT maize: Summary of average gross farm income impacts 1996–2015 ($/hectare).

In 2015, the total global farm income gain from using this technology was $1.8 billion with the cumulative gain over the period 1996–2015 being $11.1 billion. Within this, $3.44 billion (31%) was due to yield gains and the rest derived from lower costs of production.

GM HT Cotton

The use of GM HT cotton delivered a gross farm income gain of about $116.7 million in 2015. In the 1996–2015 period, the total gross farm income benefit was $1.77 billion. As with other GM HT traits, these farm income gains have mainly arisen from cost savings (73% of the total gains), although there have been some yield gains in Argentina, Brazil, Mexico and Colombia (Table 3).

TABLE 3. GM HT cotton summary of average gross farm income impacts 1996–2015 ($/hectare).

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Other HT Crops

GM HT canola (tolerant to glyphosate or glufosinate) has been grown in Canada, the US, and more recently Australia, while GM HT sugar beet is grown in the US and Canada. The gross farm income impacts associated with the adoption of these technologies are summarised in Table 4. In both cases, the main farm income benefit has derived from yield gains. In 2015, the total global income gain from the adoption of GM HT technology in canola and sugar beet was $709 million and cumulatively since 1996, it was $5.89 billion.

TABLE 4. Other GM HT crops summary of average gross farm income impacts 1996–2015 ($/hectare).

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The main way in which these technologies have impacted on farm incomes has been through lowering the levels of pest damage and hence delivering higher yields (Table 5).

TABLE 5. Average (%) yield gains GM IR cotton and maize 1996–2015.

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The greatest improvement in yields has occurred in developing countries, where conventional methods of pest control have been least effective (eg, reasons such as less well developed extension and advisory services, lack of access to finance to fund use of crop protection application equipment and products), with any cost savings associated with reduced insecticide use being mostly found in developed countries. These effects can be seen in the level of farm income gains that have arisen from the adoption of these technologies, as shown in Table 6.

TABLE 6. GM IR crops: Average gross farm income benefit 1996–2015 ($/hectare).

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At the aggregate level, the global gross farm income gains from using GM IR maize and cotton in 2015 were $4.46 billion and $3.27 billion respectively. Cumulatively since 1996, the gains have been $46 billion for GM IR maize and $50.3 billion for GM IR cotton.

Aggregated (Global Level) Impacts

GM crop technology has had a significant positive impact on global gross farm income, which amounted to $15.4 billion in 2015. This is equivalent to having added 5.2% to the value of global production of the 4 main crops of soybeans, maize, canola and cotton. Since 1996, gross farm incomes have increased by $167.8 billion.

At the country level, US farmers have been the largest beneficiaries of higher incomes, realizing over $72.3 billion in extra income between 1996 and 2015. This is not technology and for several years the GM adoption levels in all 4 US crops have been in excess of 80%. Important farm income benefits ($39.1 billion) have occurred in South America (Argentina, Bolivia, Brazil, Colombia, Paraguay and Uruguay), mostly from GM technology in soybeans and maize. GM IR cotton has also been responsible for an additional $38.2 billion additional income for cotton farmers in China and India.

In 2015, 48.7% of the farm income benefits were earned by farmers in developing countries. The vast majority of these gains have been from GM IR cotton and GM HT soybeans. Over the 20 y 1996–2015, the cumulative farm income gain derived by developing country farmers was $86.1 billion, equal to 51.3% of the total farm income during this period.

The cost to farmers for accessing GM technology, across the 4 main crops, in 2015, was equal to 29% of the total value of technology gains. This is defined as the farm income gains referred to above plus the cost of the technology payable to the seed supply chain. Readers should note that the cost of the technology accrues to the seed supply chain including sellers of seed to farmers, seed multipliers, plant breeders, distributors and the GM technology providers.

In developing countries, the total cost was equal to 20% of total technology gains compared with 36% in developed countries. While circumstances vary between countries, the higher share of total technology gains accounted for by farm income in developing countries relative to developed countries reflects factors such as weaker provision and enforcement of intellectual property rights in developing countries and the higher average level of farm income gain per hectare derived by farmers in developing countries compared with those in developed countries.

Seventy-two per cent of the total income gain over the 20-year period derives from higher yields and second crop soybean gains with 28% from lower costs (mostly on insecticides and herbicides). In terms of the 2 main trait types, insect resistance and herbicide tolerance have accounted for 58% and 42% respectively of the total income gain. The balance of the income gain arising from yield/production gains relative to cost savings is changing as second generation GM crops are increasingly adopted. Thus in 2015 the split of total income gain came 84% from yield/production gains and 16% from cost savings.

Crop Production Effects

Based on the yield impacts used in the direct farm income benefit calculations above and taking account of the second soybean crop facilitation in South America, GM crops have added important volumes to global production of corn, cotton, canola and soybeans since 1996 (Table 7).

TABLE 7. Additional crop production arising from positive yield effects of GM crops.

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The GM IR traits, used in maize and cotton, have accounted for 94.7% of the additional maize production and 98.9% of the additional cotton production. Positive yield impacts from the use of this technology have occurred in all user countries, except for GM IR cotton in Australia where the levels of Heliothis sp (boll and bud worm pests) pest control previously obtained with intensive insecticide use were very good. The main benefit and reason for adoption of this technology in Australia has arisen from significant cost savings and the associated environmental gains from reduced insecticide use, when compared with average yields derived from crops using conventional technology (such as application of insecticides and seed treatments). The average yield impact across the total area planted to these traits over the 20 y since 1996 has been +13.1% for maize and +15% for cotton.

As indicated earlier, the primary impact of GM HT technology has been to provide more cost effective (less expensive) and easier weed control, as opposed to improving yields, the improved weed control has, nevertheless, delivered higher yields in some countries. The main source of additional production from this technology has been via the facilitation of no tillage production systems, shortening the production cycle and how it has enabled many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season. This second crop, additional to traditional soybean production, has added 148 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2015 (accounting for 84.9% of the total GM HT-related additional soybean production). Intacta soybeans added a further 5.84 million tonnes since 2013.

The use of crop biotechnology, by 18 million farmers in 2015, has delivered important farm income benefits over the 20-year period to 2015. The GM IR traits have mostly delivered higher incomes through improved yields in all countries. Many farmers, especially in developed countries, have also benefited from lower costs of production (less expenditure on insecticides). The GM HT technology-driven farm income gains have mostly arisen from reduced costs of production, notably on weed control. In South America, the technology has also facilitated the move away from conventional to low/no-tillage production systems and, by effectively shortening the production cycle for soybeans, enabled many farmers to plant a second crop of soybeans after wheat in the same season. In addition, second generation GM HT soybeans, now widely used in North America, are delivering higher yields, as are the new ‘stacked’ traited HT and IR soybeans being used in South America since 2013.

In relation to HT crops, over reliance on the use of glyphosate and the lack of crop and herbicide rotation by farmers, in some regions, has contributed to the development of weed resistance. To address this problem and maintain good levels of weed control, farmers have increasingly adopted more integrated weed management strategies incorporating a mix of herbicides, other HT crops and cultural weed control measures (in other words using other herbicides with glyphosate rather than solely relying on glyphosate, using HT crops which are tolerant to other herbicides, such as glufosinate and using cultural practices such as mulching). This has added cost to the GM HT production systems compared with about 10 y ago, although relative to the current conventional alternative, the GM HT technology continues to offer important economic benefits in 2015.

Overall, there is a considerable body of evidence, in peer reviewed literature, and summarised in this paper, that quantifies the positive ‘economic’ impacts of crop biotechnology. The analysis in this paper therefore provides insights into the reasons why so many farmers around the world have adopted and continue to use the technology. Readers are encouraged to read the peer reviewed papers cited, and the many others who have published on this subject (and listed in the references below) and to draw their own conclusions.

METHODOLOGY

The report is based on extensive analysis of existing farm level impact data for GM crops, much of which can be found in peer reviewed literature. Most of this literature broadly refers to itself as ‘economic impact’ literature and applies farm accounting or partial budget approaches to assess the impact of GM crop technology on revenue, key costs of production (notably cost of seed, weed control, pest control and use of labor) and gross farm income. While primary data for impacts of commercial cultivation were not available for every crop, in every year and for each country, a substantial body of representative research and analysis is available and this has been used as the basis for the analysis presented. In addition, the authors have undertaken their own analysis of the impact of some trait-crop combinations in some countries (notably GM herbicide tolerant (HT) traits in North and South America) based on herbicide usage and cost data.

As indicated in earlier papers, the ‘economic’ impact of this technology at the farm level varies widely, both between and within regions/countries. Therefore, the measurement of impact is considered on a case by case basis in terms of crop and trait combinations and is based on the average performance and impact recorded in different crops by the studies reviewed. Where more than one piece of relevant research (eg, on the impact of using a GM trait on the yield of a crop in one country in a particular year) has been identified, the findings used in this analysis reflect the authors assessment of which research is most likely to be reasonably representative of impact in the country in that year. For example, there are many papers on the impact of GM insect resistant (IR) cotton in India. Few of these are reasonably representative of cotton growing across the country, with many papers based on small scale, local and unrepresentative samples of cotton farmers. Only the reasonably representative research has been drawn on for use in this paper – readers should consult the references to this paper to identify the sources used.

This approach may still both, overstate, or understate, the impact of GM technology for some trait, crop and country combinations, especially in cases where the technology has provided yield enhancements. However, as impact data for every trait, crop, location and year data are not available, the authors have had to extrapolate available impact data from identified studies to years for which no data are available. In addition, if the only studies available took place several years ago, there is a risk that basing current assessments on such comparisons may not adequately reflect the nature of currently available alternative (non GM seed or crop protection) technology. The weaknesses. To reduce the possibilities of over/understating impact due to these factors, the analysis:

- Directly applies impacts identified from the literature to the years that have been studied. As a result, the impacts used vary in many cases according to the findings of literature covering different years. Examples where such data are available include the impact of GM insect resistant (IR) cotton: in India (see Bennett et al. (2004); IMRB (2006) and IMRB (2007)), in Mexico (see Traxler andGodoy-Avila (2004) and Monsanto Mexico annual monitoring reports submitted to the Ministry of Agriculture in Mexico) and in the US (see Sankala and Blumenthal (2003, 2005), Mullins and Hudson (2004)). Hence, the analysis takes into account variation in the impact of the technology on yield according to its effectiveness in dealing with (annual) fluctuations in pest and weed infestation levels;

- Uses current farm level crop prices and bases any yield impacts on (adjusted – see below) current average yields. This introduces a degree of dynamic analysis that would, otherwise, be missing if constant prices and average yields identified in year-specific studies had been used;

- It includes some changes and updates to the impact assumptions identified in the literature based on new papers, annual consultation with local sources (analysts, industry representatives, databases of crop protection usage and prices) and some 'own analysis' of changes in crop protection usage and prices;

- Adjusts downwards the average base yield (in cases where GM technology has been identified as having delivered yield improvements) on which the yield enhancement has been applied. In this way, the impact on total production is not overstated.

Detailed examples of how the methodology has been applied to the calculation of the 2015 y results are presented in Appendix 1. Appendix 2 also provides details of the impacts and assumptions applied and their sources.

Other aspects of the methodology used to estimate the impact on direct farm income are as follows:

- Where stacked traits have been used, the individual trait components were analyzed separately to ensure estimates of all traits were calculated. This is be) available and used by farmers and there are studies that have assessed trait-specific impacts;

- All values presented are nominal for the year shown and the base currency used is the US dollar. All financial impacts in other currencies have been converted to US dollars at prevailing annual average exchange rates for each year (source: United States Department of Agriculture Economics Research Service);

- The analysis focuses on changes in farm income in each year arising from impact of GM technology on yields, key costs of production (notably seed cost and crop protection expenditure but also impact on costs such as fuel and labor. Inclusion of these costs is, however, more limited than the impacts on seed and crop protection costs because only a few of the papers reviewed have included consideration of such costs in their analysis. In most cases the analysis relates to impact of crop protection and seed cost only, crop quality (eg, improvements in quality arising from less pest damage or lower levels of weed impurities which result in price premia being obtained from buyers) and the scope for facilitating the planting of a second crop in a season (eg, second crop soybeans in Argentina following wheat that would, in the absence of the GM HT seed, probably not have been planted). Thus, the farm income effect measured is essentially a gross margin impact (impact on gross revenue less variable costs of production) rather than a full net cost of production assessment. Through the inclusion of yield impacts and the application of actual (average) farm prices for each year, the analysis also indirectly takes into account the possible impact of GM crop adoption on global crop supply and world prices.

The paper also includes estimates of the production impacts of GM technology at the crop level. These have been aggregated to provide the reader with a global perspective of the broader production impact of the technology. These impacts derive from the yield impacts and the facilitation of additional cropping within a season (notably in relation to soybeans in South America). Details of how these values were calculated (for 2015) are shown in Appendix 1.

DISCLOSURE OF POTENTIAL CONFLICTS OF INTEREST

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Appendix 1: Details of methodology as applied to 2015 farm income calculations

GM IR corn (targeting corn boring pests) 2015

Table

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GM IR maize (targeting maize rootworm) 2015

Table

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GM IR cotton 2015

Table

GM HT soybeans 2015 (excluding second crop soybeans – see separate table)

Table

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GM IR/HT (Intacta) soybeans 2015

Table

Download CSV Display Table

GM HT corn 2015

Table

Download CSV Display Table

GM HT cotton 2015

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Download CSV Display Table

GM HT canola 2015

Table

Download CSV Display Table

GM virus resistant crops 2015

Table

Download CSV Display Table

GM herbicide tolerant sugar beet 2015

Table

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Second soybean crop benefits: Argentina

An additional farm income benefit that many Argentine soybean growers have derived comes from the additional scope for second cropping of soybeans. This has arisen technology which has been an important factor facilitating the use of no and reduced tillage production systems. In turn the adoption of low/no tillage production systems has reduced the time required for harvesting and drilling subsequent crops and hence has enabled many Argentine farmers to cultivate 2 crops (wheat followed by soybeans) in one season. As such, the proportion of soybean production in Argentina using no or low tillage methods has increased from 34% in 1996 to 90% by 2005 and has remained at over 90% since then.

Farm level income impact of using GM HT soybeans in Argentina 1996–2015 (2): Second crop soybeans

Table

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Base yields used where GM technology delivers a positive yield gain

To avoid over-stating the positive yield effect of GM technology (where studies have identified such an impact) when applied at a national level, average (national level) yields used have been adjusted downwards (see example below). Production levels based on these adjusted levels were then cross checked with total production values based on reported average yields across the total crop.

Example: GM IR cotton (2015)

Table

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Appendix 2: Impacts, assumptions, rationale and sources for all trait/country combinations

IR corn (resistant to corn boring pests)

Table

Readers should note that the assumptions are drawn from the references cited supplemented and updated by industry sources (where the authors have not been able to identify specific studies). This has been particularly of relevance for some of the herbicide tolerant traits more recently adopted in several developing countries. Accordingly, the authors are grateful to industry sources which have provided information on impact, (notably on cost of the technology and impact on costs of crop protection). While this information does not derive from detailed studies, the authors are confident that it is reasonably representative of average impacts; in several cases, information provided from industry sources via personal communications has suggested levels of average impact that are lower than that identified in independent studies. Where this has occurred, the more conservative (industry source) data has been used.